1/3

(12) UK Patent Application (19) GB (11) 2 080 027 A

(21) Application No 8121327
(22) Date of filing 10 Jul 1981
(30) Priority data
(31) 4468/80
(32) 10 Jul 1980
(33) Australia (AU)
(43) Application published
27 Jan 1982
(51) INT CL^3
H01L 21/428 H01J
37/317//37/08 37/22
37/075
(52) Domestic classification
H1K 1EB 2S1D 2S20
2S2D 2S2P 3E5A 3R1 8VE
9D1 LCA
H1D 14A 14B 14C 17A4
17AY 18L2 18L3 18L5
18LY 19X 19Y 44
(56) Documents cited
None
(58) Field of search
H1K
(71) Applicant
Hughes Technology
Limited,
59 Wilshire Street,
Dickson, Australian
Capital Territory, 2602
Australia
(72) Inventor
John Leonard Hughes
(74) Agents
Withers & Rogers,
4 Dyer's Building,
Holborn, London,
EC1N 2JT

(54) Laser Particle Generator

(57) This invention concerns a system for laser beam activation of a target which is partly ionized in the process with the ionized constituents being directed back along the axis of the incident laser beam such that they can be analysed, or energised in such a manner that in their energised state they can be used either to anneal solids, or be implanted into said solids, consisting of a rotatable target 5, a laser beam generator 6, means 9, 10, of focussing said laser beam onto said target in such a manner as not to hinder the propogation of the emitted, ionized constituents 12 of said target, and means 11, 13 of energising said ionized components of said target to a level such that they can be implanted into or used to anneal portions of, or the whole of solids 16 placed in the path of said ionized constituents. The invention is particularly useful for implanting silicon wafers with phosphorous ions.

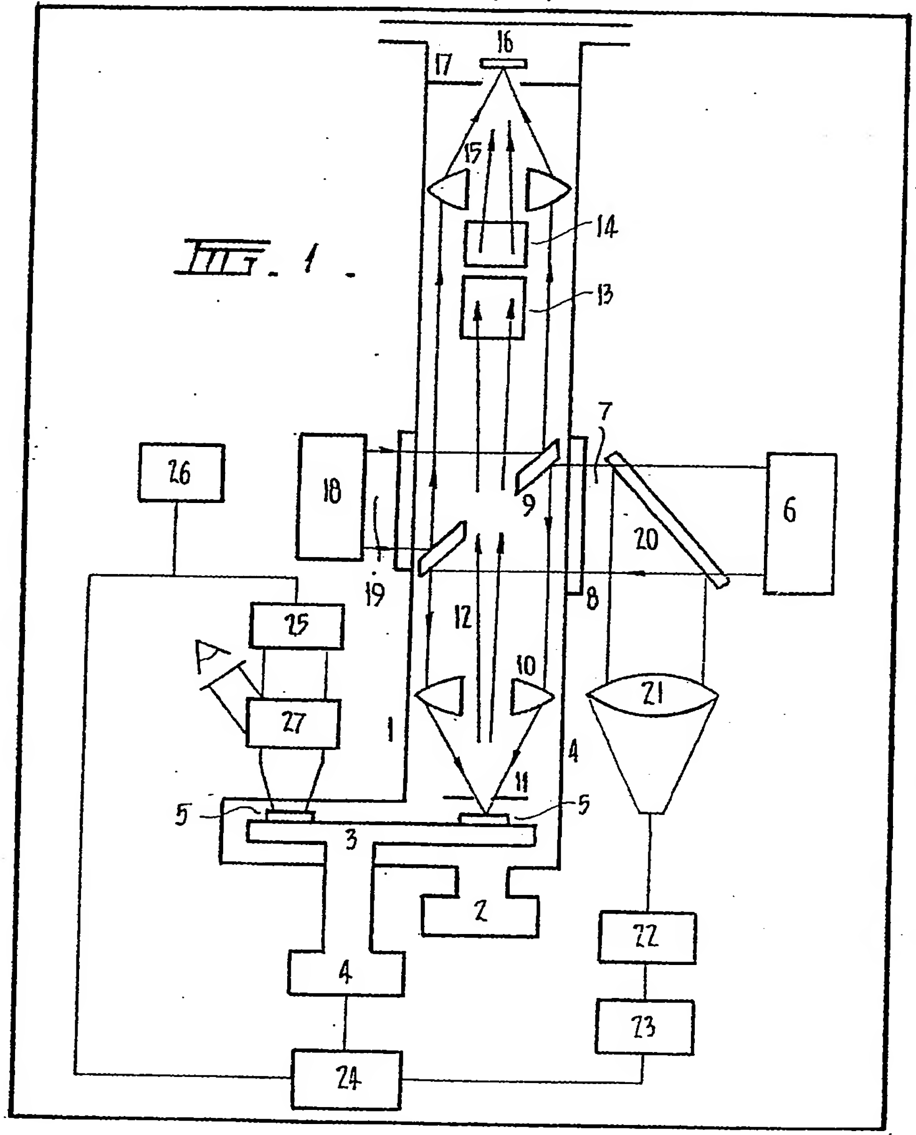
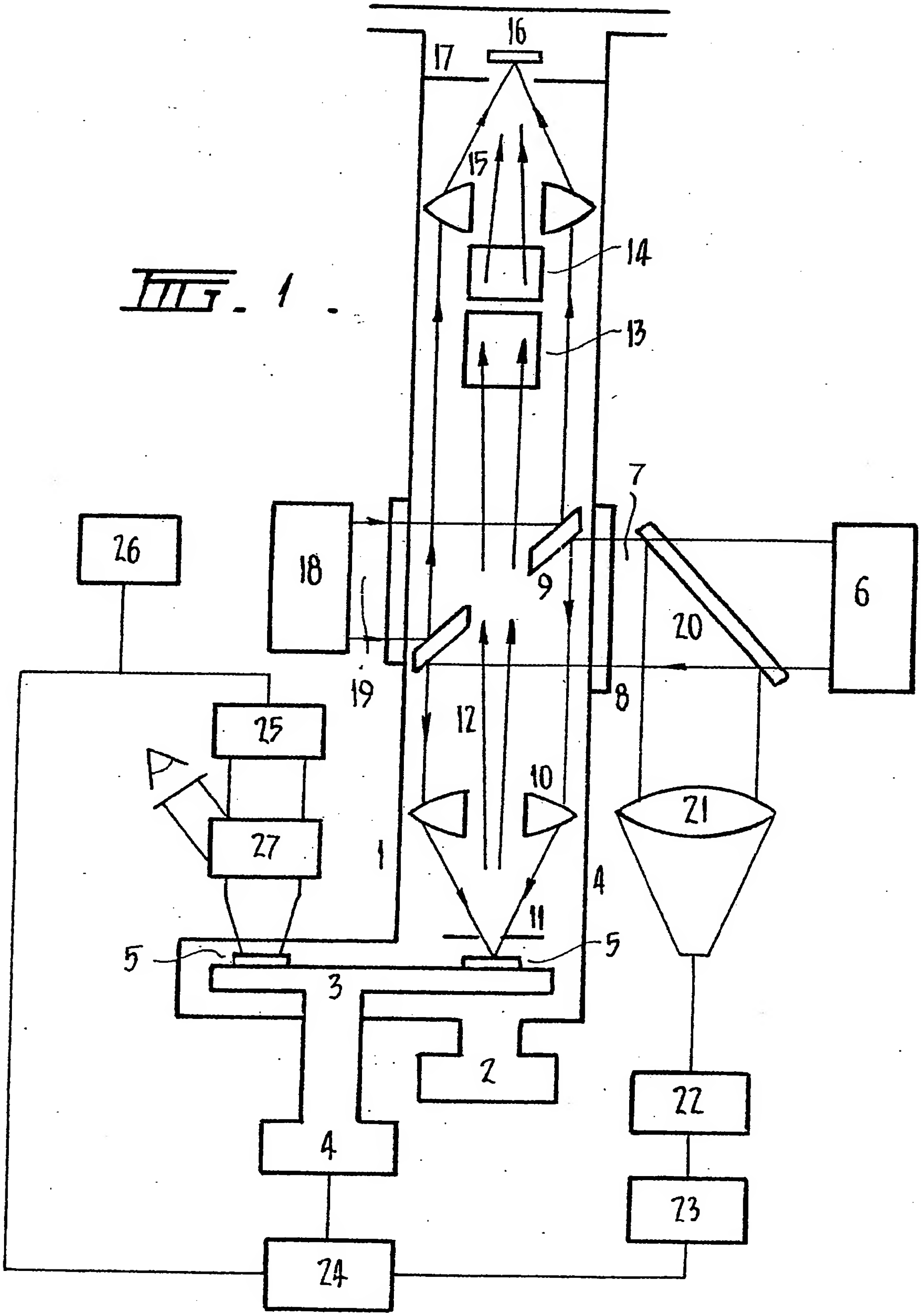


Fig. 1.

GB 2 080 027 A

FIG. 1.



2080027

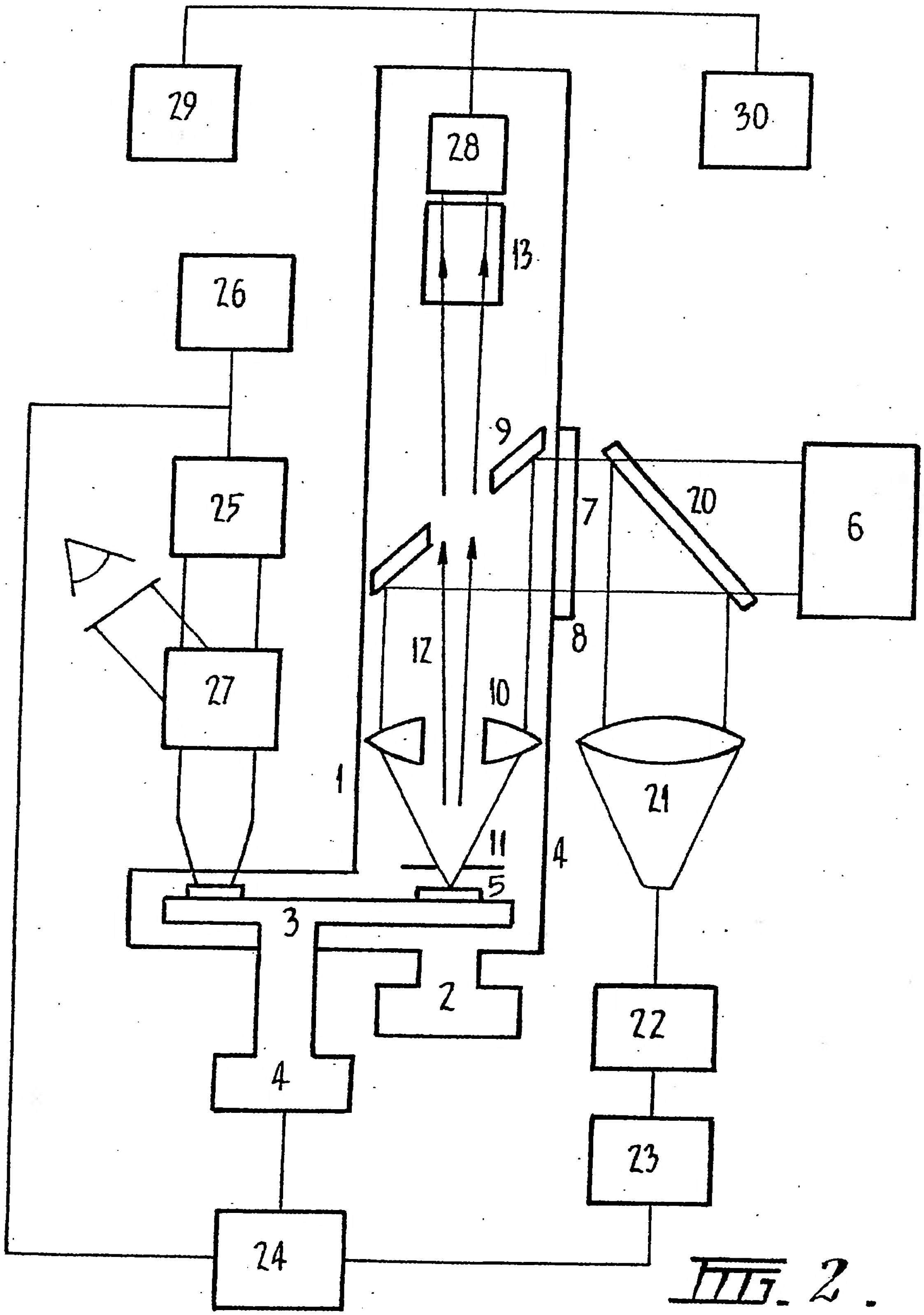


FIG. 2.

SPECIFICATION
Laser Particle Probe

Field of the Invention

This invention relates to a system for laser beam activation of a target which is partly ionized in the process with the ionized constituents being directed back along the axis of the incident laser beam such that they can be analysed, or energised in such a manner that in their energised state they can be used either to anneal solids, or be implanted into said solids, consisting of a rotatable target, a laser beam generator, means of focussing said laser beam onto said target in such a manner as not to hinder the propogation of the emitted, ionized constituents of said target, and means of energising said ionized components of said target to a level such that they can be implanted into or used to anneal portions of, or the whole of solids placed in the path of said ionized constituents.

This invention allows for either the micro-analysis of laser beam irradiated specimens or the ion implantation of semiconductors and the subsequent annealing of the implantation damage via laser or electron beam pulses.

Background of the Invention

This invention is based on extensive theoretical and experimental studies that were carried out, and directed, into the interactions of focussed laser beams with solid targets over the past fifteen years.

When a laser beam of even modest peak power, several megawatts, is focussed onto a solid surface, a crater up to several hundred microns diameter can be formed by vapourizing the surface material into its ionized state, the degree of ionization depending on the peak power and focus spot diameter of the laser beam and the properties of the irradiated solid.

Below a flux density of about 10^{12} watts cm^{-2} at a laser beam wavelength of 1 micron (1×10^{-4} cm) all solid surfaces are vapourized and ionized, the degree of ionization being a function of both the laser beam parameters and the atomic constituents of the solid material being irradiated. During the early 1960's considerable interest was generated by the observation of relatively energetic ions being emitted from solid surfaces being irradiated with laser beams of relatively low power. During the early 1970's it was shown that atoms, such as gold, which could be ionized into highly charged states under the action of intense, focussed laser beams, could be accelerated out of the solid surface, laser induced crater at energies of several MeV (6.4MeV). A transition from relatively low ion energy of several KeV to several MeV was found to occur around 10^{14} watts cm^{-2} at 1.06 microns.

The major problem from the experimental viewpoint was to ensure that the ionized constituents of the irradiated solid propogated along the axis of the laser beam in which direction the effect was greatest. This lead to the introduction of annular optics into the solid irradiation system so that the ionized constituents could propogate unhindered along the axis of the irradiating laser beam without being deflected, blocked or absorbed by the optical elements used to focus the laser beam used to irradiate the solid in the first place. In this invention, the quantity of separated ions and electrons is more important than their energy, that is to say the laser beam is not utilized as a prime accelerator of the ionized constituents of the vapourized solids. Once the ions and electrons have been generated within the above the irradiated crater in the said solid surface, the next stage is to ensure that the required constituent, be it ions or electons, is separated from the laser generated plasma. This is achieved by providing an accelerating voltage gradient which energises and directs the appropriate charged species whilst repelling the other. For example if the solid is at a positive potential whilst the accelerating electrode is at a negative potential, then ions will be repelled by the solid accelerated towards the accelerating electrode whilst the electrons will be attracted to the solid and repelled by the accelerating electrode.

The unique advantages of laser beam induced ion and electron sources are their peak power and particle densities. Furthermore, laser induced ions can be produced with very high charge states, that is to say in excess of 30+ charges.

Description of the Prior Art

Prior art systems come in several configurations. Firstly, laser probes are commercially available in which a low power laser beam is focussed by conventional microscope optical arrangements such that biological or other samples under test are irradiated and vapourized, with the emitted ions being accelerated away from the specimen under test along the path of incidence of the laser beam. These emitted ions are then analysed and identified via techniques well known in the art. Such prior art laser probes are limited to relatively low power due to the use of conventional microscope optics and the specimen under test must be very thin and precisely mounted otherwise the ions cannot be emitted into the mass spectrometer system which is positioned on the opposite side of the specimen under test to the laser focussing and viewing optics. In prior art systems coaxial optics are used to view, and fire the laser pulse onto the target.

Secondly, prior art laser induced ion sources are in the experimental stage as far as the generation of thermalised ions are concerned being composed of a lens to focus the laser beam on to the solid surface such that the ions are emitted essentially over a hemisphere with no attempt being made to channel their emission along the axis of the incident laser beam. For high energy ions generated via the action of non-linear radiation pressure gradient effects set up by the intense, focussed laser beam near the surface of

the irradiated solid, the present inventor and his co-workers invented optical arrangements whereby the solid target is rear-excited such that the ions (and electrons) emitted propogated along the axis of the incident laser beam and out via a hole in the rear focussing lens or mirror as the case may be.

Summary of the Invention

The subject invention is an apparatus for directing and focussing a laser beam, via annular optics, onto a solid surface which, over dimensions of between one and several hundred microns is vapourized into its ionized constituents forming a crater, the selected ionized constituent being directed, via appropriate voltage gradients, to propagate back, along the path of incidence of the focussed laser beam via the hole in the reflecting and focussing optical elements into a charged particle accelerator from which they emerge, energised, and capable of either being directed into a mass spectrometer or into, or onto, a solid surface for either implantation or annealing processes to take place. Furthermore, a second laser beam reflected off the rear surface of the annular reflecting optical component can also be used for post annealing of the implanted specimen.

One object of this invention is to provde an intense source of ions with high temporal resolutions and low energy spread of the type required for the large scale implantation of silicon wafers such as those used for solar cell manufacture or used in micro-electronic circuits. A particular example of such an ion source would be that corresponding to a solid target of phosphorous.

Another object of this invention is to provide an intense source of electrons with high temporal resolution and low energy spread of the type required for the large scale annealing of implanted semiconductor wafers such as those used for solar cell manufacture or used in micro-electronic circuits.

Another object of the invention is to provide means for annealing implanted wafers with a laser pulse.

Another object of the invention is to energise laser induced charged particles via compact accelerators prior to the implantation or annealing processes.

Another object of this invention is to accurately position a given area of the target in the focus of the laser beam.

Another object of the invention is to provide means of analysing the laser induced ions emitted from the target, via a mass-spectrometer.

Another object of the invention is to provide a source of ions for such applications as ion beam thrusters for space vehicles so that they may be accelerated to high velocities over relatively long periods as they traverse the solar system.

Broadly this invention provides apparatus for generating, selecting and energising laser, ion and electron beams for the implantation and annealing of semiconductor wafers comprising:

means for directing a laser pulse via an annular reflector and annular lens to focus on the surface of a rotatable target to produce a dense plasma composed of the ionized constituents of the target material;

means for selecting the required charged particle species from the dense, laser produced plasma of the target material and directing said charged particles through the annular optical components coaxially, but in the opposite direction to the irradiating laser beam;

means for accelerating and collimating selected charged particle species so that they impinge on a semiconductor wafer and either become implanted in it or dissipate their energy to anneal its implanted surface; and

means for directing a second laser pulse onto the said semiconductor wafer to anneal any implantation damage.

In a preferred embodiment, this invention provides an apparatus for generating ion beams with densities of between 10^{12} and 10^{17} ions per pulse with ion energies in the range 10KeV to 1GeV depending on the peak power of the input laser pulse, the focus spot diameter on target, the nature of the target and the parameters of the particle accelerator. Also in a preferred mode of the invention, means are available to suppress the emission of electrons when an ion pulse is required and for suppressing the emission ions where an electron pulse is required. Means are also available in a preferred form of the invention for using a second pulse to anneal a silicon wafer after it has been implanted with the appropriate ion.

In this simplest configuration this invention consists of an evacuated housing with two laser beam input windows, a double sided, annular laser beam reflector, and annular lens which focusses the laser pulses onto the surface of a rotating ring of the target material mounted onto a turntable which can be both driven and controlled external to the evacuated housing. Above the ring target is positioned an annular disc such that the potential difference between the target ring and the annular disc attracts or repels ions depending on whether ion or electron pulses are required to be energised in the compact particle accelerator mounted coaxially with the emitted charged particles but on the opposite side of the annular reflector and lens. Means are also included for either analysing the masses of the ions or directing them onto the surface of the wafers to be implanted with said ions.

Since the aim is to generate as many ions or electrons as possible per incident laser pulse on the target ring, it follows that the mean energy of said ions and electrons will be relatively low. To provide the charged particle energies required for ion implantation and electron pulse annealing it is necessary to accelerate said charged particles through the compact accelerators so that they emerge with energies up to several hundred kilo-electron volts in their respective pulses.

Used as a specimen probe, this invention incorporates means of viewing a particular area of the target ring, then means of rotating said ring through 180° so as to position the viewed area accurately within the laser focus spot.

Used as an ion or electron pulse generator, this invention incorporates means of adjusting the relative positions of the ring target and the laser focus spot so that clean, uncratered positions of the rotating target ring can be presented to the focussed laser beam as required. Means is provided for observing the irradiated target ring via the laser beam focussing optics. Means are also provided for positioning and removing silicon and other wafers for implantation and annealing.

Brief Descriptions of the Several Views of the Drawings

A better understanding of the invention will be gained from the following description taken in conjunction with the drawings.

In the drawings:

Figure 1 shows a preferred arrangement set up for the implantation and annealing of silicon wafers;

Figure 2 shows another arrangement of the invention for use as a laser probe for the analysis of unknown targets and structures.

Detailed Description

Now having particular regard to the numerals on the drawings, 1 indicates an evacuated housing, evacuated by vacuum pump 2. Numeral 3 indicates a rotating table driven by motor assembly 4. Numeral 5 indicates a flat ring of the target material which is attached to turntable 3. Means of fine adjusting turntable 3 and of inserting the annular target ring 5 into the chamber 1 are not shown.

Numeral 6 indicates the laser pulse generator which emits laser pulse along beam path 7 via optically polished window 8 into evacuated chamber 1 where it is reflected off the lower surface of a 45° orientated double sided, annular reflector 9 and focussed onto the surface of target ring 5 via annular lens 10.

The dense plasma induced on target ring 5 by focussed laser pulse 7 responds to the polarity of the voltage gradient between target ring 5 and annular disc electrode 11. Depending on whether the polarity of annular disc electrode 11 is positive or negative, electrons or ions (indicated by numeral 12) respectively will be channelled via the hole in lens 10 and reflector 9 into the compact charged particle accelerator 13 whose voltage gradients is matched to the positive or negative particles that have to be energised.

Numeral 14 indicates a charged particle collimation assembly which directs the energised charged particles via the hole in annular lens 15 onto the silicon wafer indicated by numeral 16 which can be positioned in, and removed from the evacuated enclosure 17 which can be evacuated independently of housing 1.

Numeral 18 indicates a second laser beam generator whose pulsed, or continuous wave, output is directed into housing 1 via optically polished window 19 where it is reflected off the upper surface of annular mirror 9 onto the surface of the silicon wafer 16 via annular lens 15.

Numeral 20 indicates an optically flat beam splitter which allows the use of optical components 9 and 10 to view the surface of target ring 5 via the T.V. monitoring assembly indicated by numerals 21, 22 and 23 where numeral 21 indicates a motorised zoom lens, numeral 22 a T.V. camera and numeral 23 a T.V. display monitor. Numeral 24 indicates a control box where the inputs of T.V. viewing assemblies 21, 22, 23 and 25, 26, 27 can be compared and turntable motor assembly 4 adjusted accordingly.

Figure 2 shows the invention operating as a scientific probe and is almost of identical configuration to the configuration of Figure 1 except that charged particle collimator indicated in Figure 1 by numeral 14 is replaced in Figure 2 by a mass-spectrometer indicated by numeral 28. Furthermore, the silicon wafer manipulation devices and location chamber have also been removed together with the second laser beam generator.

In the configuration of this invention shown in Figure 2, the region of target 5 viewed via microscope assembly 27, 25, 26 should be positioned accurately in the focus region of laser beam 7 via T.V. assembly 21, 22, 23 and control unit 24.

The ions emitted via the laser beam irradiation of target 5 are then analysed via the mass-spectrometer assembly indicated by numerals 13 and 28. The results can be recorded, either on chart record 29 or oscilloscope assembly 30.

It is emphasised that the above teachings are exemplary and not limitative of the scope and applicability of the invention.

A particular use of the present invention is to implant silicon wafers with phosphorous ions at a rate which exceeds the reported capacity of state of the art ion beam accelerator implanters. For example, laser ion generation direct from solid targets can deliver up to 10^{13} ions per second. At a pulse repetition rate of 10,000 cycles per second, it is now possible to implant over 10^{17} ions per second. In fact the major limitations of this invention is the gradual buildup of excess phosphorous ions within the evacuated housing and the limitations of placing and removing the silicon wafers, or any other implantable wafer in, and from, the implanting site. However, techniques to improve these defects which currently limit the effectiveness of this invention are known in the art and when improved will lead to an improvement in this invention. Ultimately, up to 600 cm^2 per second of silicon solar cell surface can be implanted and annealed with this invention. This achievement would reduce the cost of silicone solar cell production by several orders of magnitude over conventional methods and thus make a significant contribution to easing the burden of the current "energy crises".

Operated as a laser probe for the analysis of the mass of the emitted ions, this invention allows for separate optics for viewing and irradiating the target area. This arrangement allows higher laser beam powers and a wider range of laser beam wavelengths to be used for specimen analysis. Furthermore, there is no danger of any laser radiation leaking into the eye of the observer as could be the case with common optical arrangements.

Since no known material can withstand the effects of intense, focussed laser beams, the reflectivity of various targets as a function of laser wavelengths is not critical because the surface is destroyed in a relatively short period compared to the duration of the laser pulse. Normally, pulses used in this invention, that is laser pulses, ion pulses or electron pulses have duration ranging from nanoseconds (10^{-9} secs) to microseconds (10^{-6} seconds). The laser pulse itself may have durations of about 50 nanoseconds whilst the ion and electron pulses could have durations extending over several microseconds. Since only a minute thickness of the silicon wafer is implanted with phosphorous ions, it takes only a few microseconds to anneal out the damage caused by the implantation process. This can be done in this invention either with electron pulses, laser pulses or both, sequentially or simultaneously.

Since the invention does not depend on the transmission of charged particles through their membranes as was the case with the prior art systems, much thicker specimens may be analysed.

In addition to silicon wafers doped with phosphorous ions the invention allows for doping with ions of any solid material which can be mounted on the turntable. Furthermore, the wafer being doped may be of any suitable material, for example arsenic or gallium.

In addition to solar cell manufacture, the invention allows for the implantation and annealing of a wide range of micro-electronic circuit components and photo-detectors. State of the art techniques to further manipulate the ion or electron pulses may be added to the invention without detracting from its basic properties, for example, precision ion beam scanner may be added so that the wafers are implanted in a set pattern.

This invention is capable of being used as an ion source in an ion beam space-craft engine where the thrust imparted to the craft by the ejected ions can accelerate said craft to relatively high velocities as it traverses out solar system.

My invention can also be used as a source of charged particles for large accelerators.

Although the preferred embodiments of my invention have been shown and described herein, it should be clear that modification and variation may be made without departing from what is considered to be the invention.

Claims

1. Apparatus for generating, selecting and energising laser, ion and electron beams for the implantation and annealing of semiconductor wafers comprising:

means for directing a laser pulse via an annular reflector and annular lens to focus on the surface of a rotatable target to produce a dense plasma composed of the ionized constituents of the target material;

means for selecting the required charged particle species from the dense, laser produced plasma of the target material and directing said charged particles through the annular optical components coaxially, but in the opposite direction to the irradiating laser beam;

means for accelerating and collimating selected charged particle species so that they impinge on a semiconductor wafer and either become implanted in it or dissipate their energy to anneal its implanted surface; and

means for directing a second laser pulse onto the said semiconductor wafer to anneal any implantation damage.

2. Apparatus as claimed in Claim 1 consisting of an evacuated housing containing a rotatable target, annular electrode, annular lens, annular 45° orientated, double sided laser beam reflector, compact charged particle accelerator, charged particle collimator, secondary laser beam focussing lens and semiconductor wafer manipulator.

3. Apparatus as claimed in claim 2 with the rotatable target and annular electrode positioned on the opposite side of an annular lens to an annular, 45° orientated, double sided laser beam reflector, compact charged particle accelerator, charged particle collimator, secondary laser beam focussing lens and semiconductor wafer manipulator.

4. Apparatus as claimed in claim 2 where the target ring material is phosphorous.

5. Apparatus for generating and energising laser ion and electron beams for the implantation and annealing of semi-conductor wafers, constructed and arranged substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

6. A method of implanting and annealing semiconductor wafers comprising:

directing a laser pulse via an annular reflector and annular lens to focus on the surface of a rotatable target to produce a dense plasma composed of the ionized constituents of the target material;

selecting the required charged particle species from the dense, laser produced plasma of the target material and directing the charged particles through the annular optical components coaxially, but in the opposite direction to the irradiating laser beam;

accelerating and collimating selected charged particle species so that they impinge on a

semiconductor wafer and either become implanted in it or dissipate their energy to anneal its implanted surface; and

directing a second laser pulse onto the semiconductor wafer to anneal any implantation damage.

7. A method according to claim 6 where the target ring material is phosphorous.

8. A method of implanting and annealing semiconductor wafers substantially as herein before described.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1982. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.